Predictive Model for weight loss using Monte Carlo simulations

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Code : Github Link

Objective

- Weight loss is a common goal for many individuals, yet achieving it effectively remains a challenge due to individual variability in responses to sleep and exercise.
- Traditional fitness plans often assume a one-routine-fits-all approach, leading to inconsistent results.
- This project aims to design a Monte Carlo simulation model that incorporates key factors like workout type, intensity, duration, metabolic rate, sleep duration and caloric intake to predict weight loss outcomes.

3 Stages of the MC Simulation

Stage 1 – Design

Variables that affect the system and their distribution:

Input Variables:

- User Attributes: age, height, weight, calorie intake, gender.
- Activity MET Values and Duration
- Additional Factors: workout days, additional calories burned from non-workout activities, sleep duration.

Defined Distributions for Random Variables:

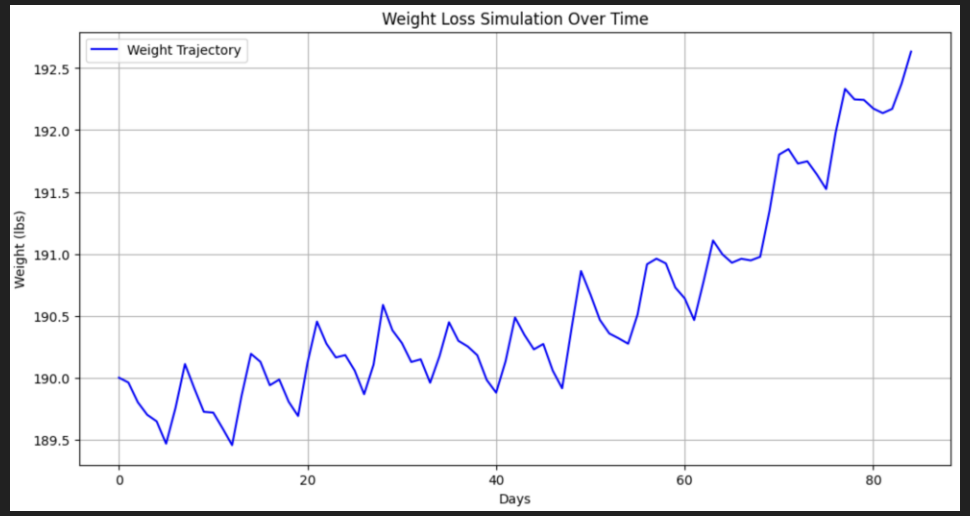
- Workout Days per Week: Uniform distribution between 2 and 7.
- Additional Calories Burned: Uniform distribution between 200 and 700 kcal.
- Calorie Intake Variation: Uniform random variation of ±500 kcal around the user's base calorie intake.
- Sleep Duration Variation: Uniform random variation of ±2 hours around the user's average sleep duration.

The relationship between these inputs and the output (weight change):

- Resting Metabolic Rate (RMR): Calculated using the weight, height, age, gender.
- Calories Burned from Activities: Using MET values and activity durations.
- Weight Change: Derived from calorie deficits or surpluses.

Stage 2 - Validation

- We validated one scenario with user inputs to check the trajectory of the graph.

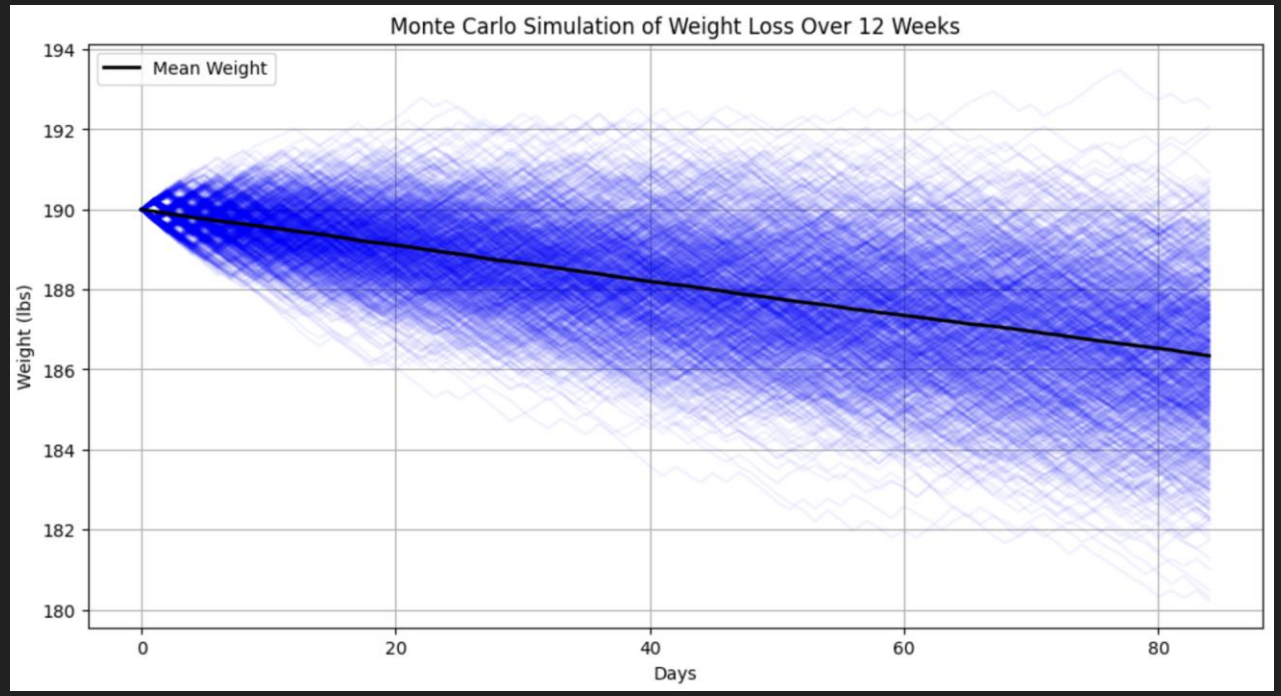


- For each simulation run, a new set of random values is generated for the random variables.
- The random sampling is repeated for the number of simulations, with each simulation spanning weeks (7 days).

3 Stages of the MC Simulation

Stage 3 – Experiment and Predictions

- Ran the simulation for many iterations.
- Introduced more random variables to experiment the simulation.
- Made variations to the fixed variables from the initial hypothesis.
- Compared the initial hypothesis with the newer ones and made conclusions



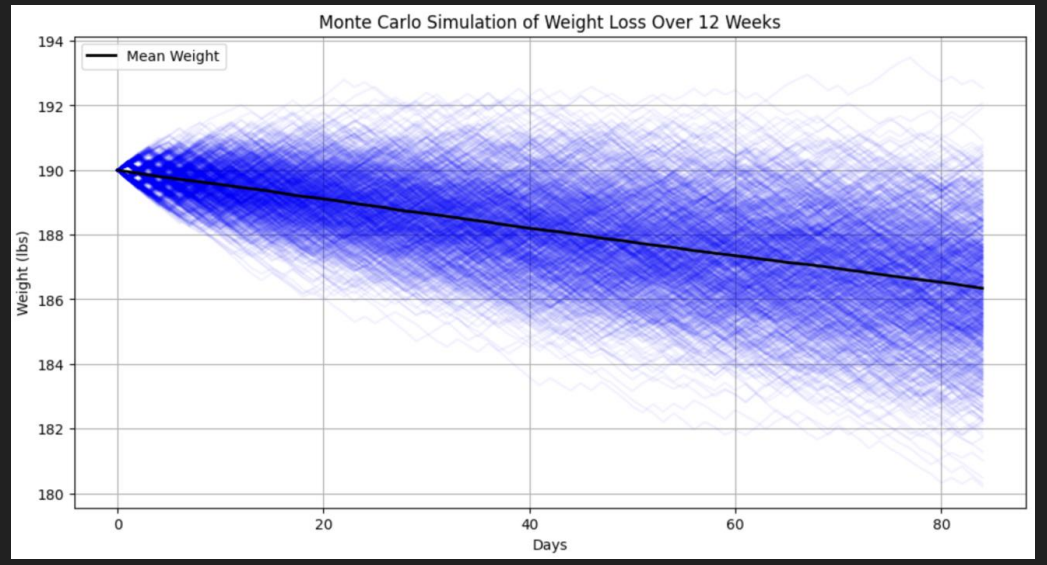
Assumptions

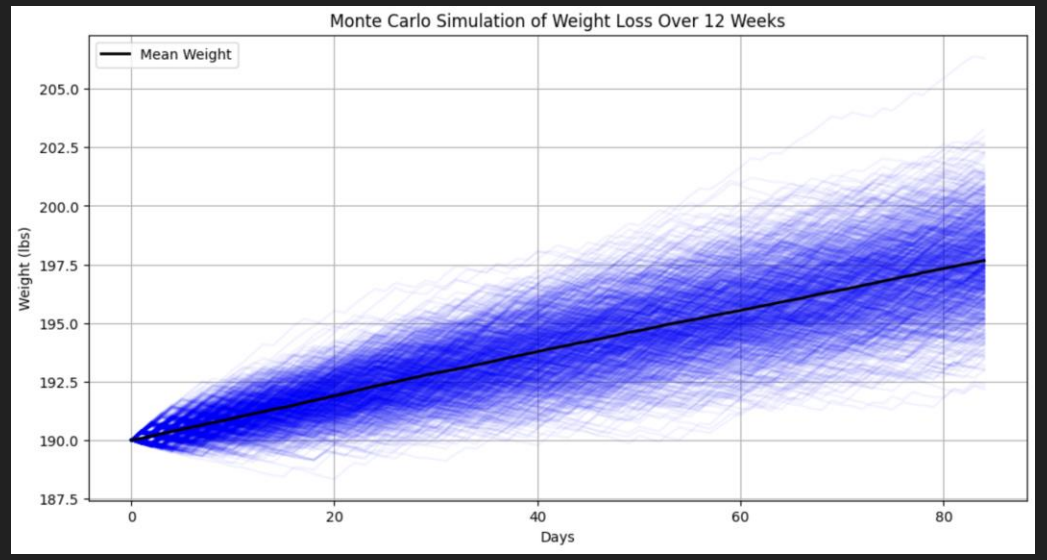
- Additional calories is the non-exercise calories that an individual might burn apart from working out and RMR
- We have assumed that all the calculations we have used referenced from the paper are correct
- We have assumed that total calories burned is only the sum of RMR + Workout Calories + Additional Calories
- We have assumed that weight loss can be derived using Calorie Deficit which is the difference of Total Calories burned and Calorie Intake

Hypothesis 1

Predicted weight loss over a fixed duration increases as the number of workout days in a week and additional calories burned (daily activity level) increase.

- A higher frequency of workout days per week and greater additional calorie expenditure will result in a larger calorie deficit, leading to more significant weight loss.
- Fixed variables such as gender, age, height, and initial weight play a critical role in determining baseline metabolic rates and caloric needs, which influence overall weight trends.





Variables used for Hypothesis 1

- **Fixed Variables (Input from the user):**

1. **Initial Weight (lbs):** Initial body weight of an individual
2. **Age, Gender, Height:** These variables influence the basal metabolic rate (RMR).
3. **Workout Duration (hours):** Number of hours a person does the workout in a day.
4. **Activity Type and Activity Intensity (MET value):** These are based on a numerical number called MET value which is different for each activity type and the intensity.
5. **Calorie Intake (kcal):** The number of calories that a person is consuming every day.

- **Random Variables:**

1. **Number of workout days in a week (days):** Total number of workout days in a week.
2. **Additional Calories Burned (kcal/day):** The number of additional calories burned per day from daily non-exercise activities.

Variables used for Hypothesis 1

- **Derived Variables:**

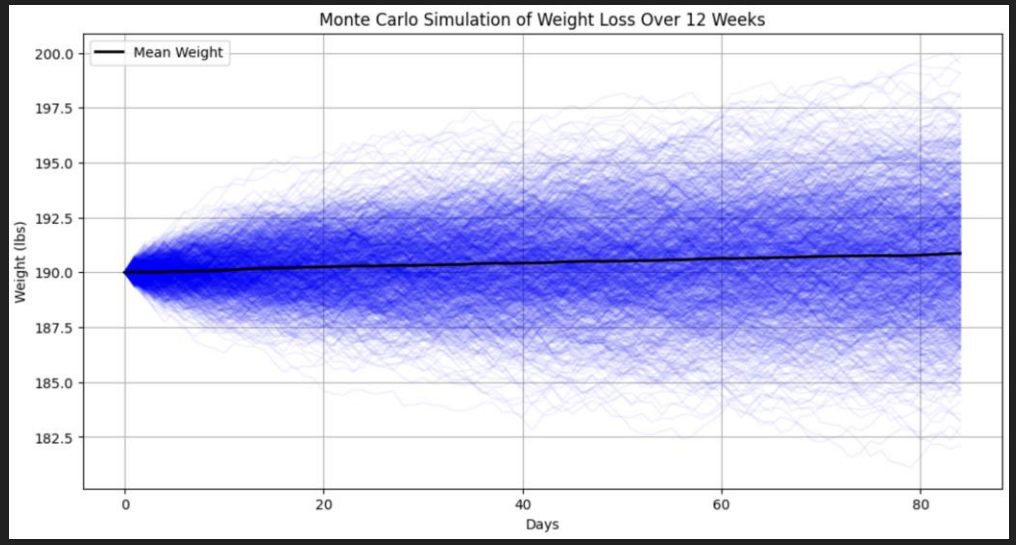
1. **Resting Metabolic Rate (RMR):** Calculated based on Age, Gender, Height, Initial Weight
2. **Workout calories (kcal)**: Calculated based on MET value, workout duration and initial weight
3. **Total Calories Burned (kcal):** Calculated based on the sum of Workout Calories, Additional Calories Burned and RMR
4. **Calorie Deficit(kcal):** Calculated based on Total Calories Burned(kcal) and Calorie intake(kcal)
5. **Predicted Weight Loss(lbs):** Calculated by converting the calories into weight factor

Conclusion (Hypothesis 1)

- **Hypotheses 1:** The Monte Carlo Simulation graph shows the effective realtionship between the additional calories burnt from non-exercise activites, number of workout days and predicted weight loss over a fixed duration.
- The simulation partially supports our hypotheses as it confirms that weight loss increases with an increase in the number of workout days and additional calories burnt, considering that the calorie intake is ideal for the given weight. The wide range of trajectories depict the variability due to different RMR, routine and initial conditions (like initial weight, calorie intake etc.). Calorie intake plays a very significant role in determining the weight loss of a person. Keeping it constant does not make sense in an ideal scenario.

Hypothesis 2

Consistent calorie intake, adequate sleep duration and regular workout days experience faster and more predictable weight loss, while greater variability in these factors demonstrate slower and less consistent weight loss trajectories due to fluctuations in energy balance and resting metabolic rate (RMR).



- Variations in randomized factors, such as the number of workout days, additional calories burned, sleep duration, and calorie intake will lead to a distribution of potential weight outcomes, reflecting real-life variability.
- Sleep deprivation leads to a reduction in the RMR, impacting the total calories burned and subsequent weight outcomes.

Variables used for Hypothesis 2

- **Fixed Variables (Input from the user):**

1. **Initial Weight (lbs):** Initial body weight of an individual
2. **Age, Gender, Height:** These variables influence the basal metabolic rate (RMR).
3. **Workout Duration (hours):** Number of hours a person does the workout in a day.
4. **Activity Type and Activity Intensity (MET value):** These are based on a numerical number called MET value which is different for each activity type and the intensity.

- **Random Variables:**

1. **Number of workout days in a week (days):** Total number of workout days in a week.
2. **Additional Calories Burned (kcal/day):** The number of additional calories burned per day from daily non-exercise activities.
3. **Calorie Intake (kcal):** The number of calories that a person is consuming every day.
4. **Sleep Duration (hours):** The number of hours the person is sleeping every day.

Variables used for Hypothesis 2

- **Derived Variables:**

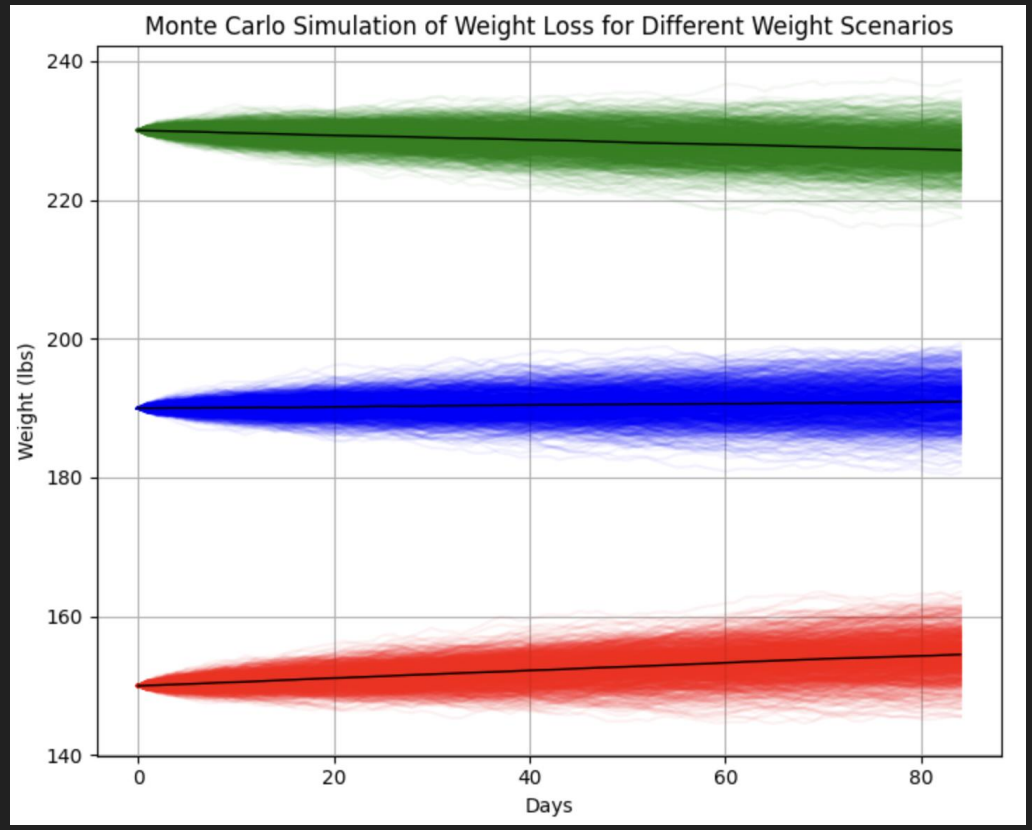
1. **Resting Metabolic Rate (RMR):** Calculated based on Age, Gender, Height, Initial Weight and sleep adjustment factor
2. **Workout calories (kcal)**: Calculated based on MET value, workout duration and initial weight.
3. **Total Calories Burned (kcal):** Calculated based on the sum of Workout Calories, Additional Calories Burned and RMR.
4. **Calorie Deficit(kcal):** Calculated based on Total Calories Burned(kcal) and Calorie intake(kcal)
5. **Predicted Weight Loss(lbs):** Calculated by converting the calories into weight factor.

Conclusion (Hypothesis 2)

- **T**he Monte Carlo simulation graph for Hypothesis 2 reveals a stronger co-relation between the random variables.
- Greater variability in the factors like workout days, sleep duration or calorie intake shows a wider spread of weight loss trajectories. These randomization cause slower and less predictable progress, as seen in the dispersion of lines in the graph. This variability also aligns with the hypothesis that inconsistency in key factors disrupts energy balance and impacts metabolic efficiency, leading to a less reliable weight loss outcome.
- Overall, the simulation supports our hypothesis while variability introduces uncertainty and slower progress.

Hypothesis 3

Predicted weight loss over a fixed duration differs among individuals with identical user details but varying initial weight offsets (+40 lbs, 0 lbs, and -40 lbs). Individuals with a positive weight offset (+40 lbs) are expected to have a flatter slope of weight loss compared to those with a negative weight offset (-40 lbs), using the individual with 0 lbs offset as the reference point.



Conclusion (Hypothesis 3)

- The Monte Carlo Simulation supports our hypothesis and the graph clearly shows that an individual's starting weight significantly impacts the predictability of weight loss.
- People with higher initial weights tend to lose weight faster and more consistently because of higher energy expenditure and a greater resting metabolic rate (RMR).
- In contrast, individuals with lower initial weights experience slower and more gradual weight loss, with greater variability in their outcomes.

Limitations

- The model assumes that calorie deficits directly translate to weight loss, ignoring factors like muscle gain, hormonal imbalances, or water retention, which can impact actual outcomes.
- Variables like calorie intake, workout duration, and sleep duration are randomized but remain constant for the simulation period, which may not fully reflect real-life fluctuations.
- The model does not account for individual physiological differences such as genetics, metabolic disorders, or varying responses to workouts and diets.
- Only MET-based activities are included, and specific variations in intensity or combined workouts (e.g., HIIT, swimming, dancing) are not explicitly included.
- While RMR adjustments for sleep variability are incorporated, other metabolic impacts of poor sleep (e.g., changes in appetite-regulating hormones) are not considered.

Future Scope

- Expanding the model to include additional factors like stress levels, hormonal changes, and hydration could provide a more comprehensive understanding of weight loss outcomes.
- Introducing specific dietary plans (e.g., high-protein, ketogenic, or intermittent fasting) as input variables could allow users to compare their effectiveness alongside exercise and sleep.
- Extending simulations to model weight loss outcomes over longer durations (e.g., months or years) while accounting for plateaus and metabolic adaptation.